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SER Minimized Relay Selection for Physical Layer Network Coding in Two-way Relay Channels

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Abstract

Relay selection of physical layer network coding (PNC) for two-way relay model is investigated in this paper. Two end nodes transmit their signals to multiple relays simultaneously, and the single relay which performs the best symbol error rate (SER) performance is selected to process the received superimposed signal and broadcast the network-coded packet to the end nodes. The SER performance of the proposed relay selection scheme is analyzed and full diversity order is derived if all the relays are used. Extensive simulations are performed and the results show that minimized SER relay selection can considerably enhance the performance of PNC two-way relay channels.

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Keywords: physical layer network coding (PNC); relay selection; SER

1. Introduction

Three-node network model is considered as one of the basic components of complex wireless networks, which has been studied so much in the field of communication. The three-node network is composed of two end nodes and a relay node. The scenario where the two end nodes exchange information via a relay is referred to as two-way relay model, which widely exists in different kinds of wireless networks, such as cellular networks and multi-hop mesh networks. Physical layer network coding (PNC) [1-3] is one of the well-known protocols for two-way relay transmission, for it just requires two time slots to accomplish one round information exchange between two end nodes. In the first time slot, two end nodes transmit their signals to relay simultaneously, and the relay processes the received signals and combines the

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superimposed signals to a network-coded packet in the second time slot. Once the two end nodes received the signal transmitted from relay, they could recover the desired signal by detection method.

Relay selection is able to enhance system performance with simple hardware, and has been used for two-way relay channel recently [4, 5]. However, to the best of our knowledge, relay selection for PNC protocol is rare in literature. A relay selection scheme has been proposed in [6] by modifying the well-known selection cooperation. The scheme firstly determines a set of relays which can correctly decode superimposed signals in the first time slot, and then a single best relay is selected such that the minimum mutual information of the two channels from each relay to A and B is maximized.

In this paper we consider the relay selection scheme to minimize PNC's SER. In this scheme, the relays do not need to know whether they decode the superimposed signals correctly or not. The main contributions of this paper are as follows. (1) Firstly, a new relay selection scheme for PNC is proposed to minimum the SER in Two-way relay channels. (2) The performance of the proposed relay selection scheme is analyzed. (3) Extensive simulations are performed and the results show that the proposed scheme can enhance the PNC's performance considerably.

The rest of this paper is organized as follows. In section 2, the model of relay selection in two-way relay PNC is expatiated. In section 3, SER of single relay PNC system is analyzed. In section 4, the relay selection scheme based on minimizing the SER performance is proposed and the performance of this scheme is investigated. In section 5, the simulation results validate the proposed relay selection scheme. The conclusion of this paper is in section 6.

2. System Model

Consider a two way relay model in PNC as shown in Fig. 1, where A and B exchange information via L relays. We use R_l denote the l-th relay for $l = 1, \cdots, L$. Transmission power at each terminal is assumed the same and denoted by P. Channel coefficient between A and R_l is denoted by h_{al}, and the channel coefficient between B and R_l is denoted by h_{bl}. It is assumed that all the channels are reciprocal and they are modelled as $h_{al} \sim \quad (0, \Omega_{ar})$ and $h_{bl} \sim \quad (0, \Omega_{br})$. It is also assumed that all the noises are complex gaussian distributed with power spectral density of $N_0 / 2$ per dimension.

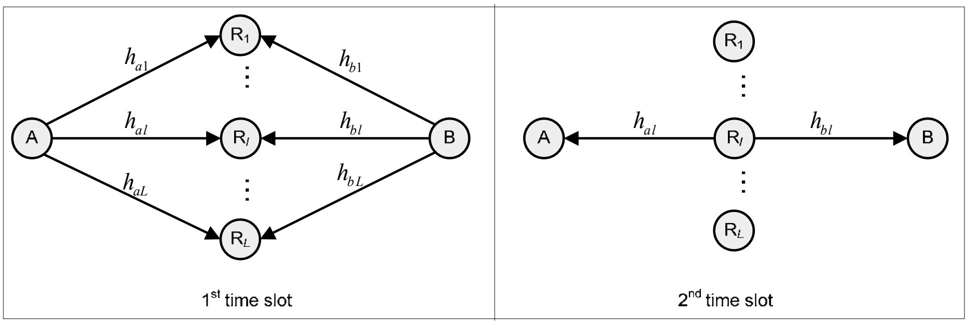

Fig. 1 System Model for the PNC Protocol with Multiple Relays.

Three steps are needed to accomplish the SER minimized relay selection for PNC in two-way relay channels.

***Step*1**: A and B transmit their signals to the L relays simultaneously, and all the L relays will receive the superimposed signal.

***Step*2**: Based on minimum SER criterion, a single relay which provides the best SER performance would be selected. We assume the selected relay is R_k.

***Step*3**: R_k detects the superimposed signal by maximum likelihood detection and combines the detected value to a network-coded packet, and then R_k broadcasts the network-coded packet to A and B. Receiving the packet from R_k and having their own information, A and B could decode their desired signal by maximum likelihood detection.

3. End-to-end SER Analysis

For the proposed relay selection scheme is based on the best SER performance, we will discuss end-to-end SER of one relay PNC in this section.

Because of noise and channel fading, two detection errors often probably happen in PNC system, and the error probability is denoted by SER. The first detection error may occur at R_l, and the SER is p_{erl}. The second detection error may occur at end node A and B, and the SER are p_{eal} and p_{ebl}.

In two-way relay system, two end-to-end one way transmission are involved. Now let us discuss the end-to-end transmission SER from A to B firstly. B may get the incorrect signal in the two cases. First, the detection at R_l is correct and detection at B is incorrect. Second, the detection at R_l is incorrect. It should be noted that B has a certain probability to get the right signal when the detections at R and B are both incorrect, and we let p_{ii} denote this probability. As a result, this part of probability should be subtracted from the second case. Thus, the end-to-end SER from A to B can be given by

$$p_{e2e-al} = (1-p_{erl})p_{eal} + p_{erl} - p_{ii}p_{erl}p_{eal}. \tag{1}$$

Similarly, the end-to-end SER from B to A can be given by

$$p_{e2e-bl} = (1-p_{erl})p_{ebl} + p_{erl} - p_{ii}p_{erl}p_{ebl}. \tag{2}$$

Thus, the end-to-end SER for single relay PNC can be calculated as

$$\begin{aligned} p_{e2el} &= \frac{1}{2}(p_{e2e-al} + p_{e2e-bl}) = \frac{1}{2}((1-p_{erl})p_{eal} + p_{erl} - p_{ii}p_{erl}p_{eal} + (1-p_{erl})p_{ebl} + p_{erl} - p_{ii}p_{erl}p_{ebl}) \\ &= p_{erl} + \frac{1}{2}p_{eal} + \frac{1}{2}p_{ebl} - \frac{1}{2}(1+p_{ii})(p_{erl}p_{eal} + p_{erl}p_{ebl}) \end{aligned} \tag{3}$$

If we let $p_{erl} = p_{eal} = p_{ebl} = p$, it can be found p_{e2el} has the same order with $p_{erl} + \frac{1}{2}p_{eal} + \frac{1}{2}p_{ebl}$. Thus, p_{e2el} can be approximate to

$$p_{e2el} = p_{erl} + \frac{1}{2}p_{eal} + \frac{1}{2}p_{ebl} \tag{4}$$

4. Performance Analysis

By calculation Eq. (4), each of the L relays is able to derive the SER if it is selected to finish the whole transmission. In order to optimal the SER performance of PNC system, a single relay R_k is selected such that the instantaneous SER is minimum. It can be given by

$$k = \arg\min_{l}(P_{erl} + \frac{1}{2}P_{eal} + \frac{1}{2}P_{ebl}). \tag{5}$$

The selection criterion could be further simplified for a certain modulation. Assume BPSK modulation is employed, p_{ea} and p_{eb} are equals with the SER of traditional BPSK modulation and it can be given by $p_{eal} = Q(\sqrt{2|h_{al}|^2 P/N_0})$ and $p_{ebl} = Q(\sqrt{2|h_{bl}|^2 P/N_0})$, respectively. And the upper and lower bounds of P_{erl} have been gotten in [7], where the upper bound is $Q(\sqrt{2|h_{al}|^2 P/N_0}) + Q(\sqrt{2|h_{bl}|^2 P/N_0})$ and the lower bound is $Q(\sqrt{2\min(|h_{al}|^2 P, |h_{bl}|^2 P)/N_0})$. It is also demonstrated the two bounds are tight by simulation result in [7]. In order to simplify the analysis, we let $p_{erl} = Q(\sqrt{2\min(|h_{al}|^2 P, |h_{bl}|^2 P)/N_0})$. Similarly, we also let $\frac{1}{2}(p_{eal}+p_{ebl})$ be approximated to $\frac{1}{2}Q(\sqrt{2\min(|h_{al}|^2 P,|h_{bl}|^2 P)/N_0})$. Thus the total end-to-end SER of PNC for BPSK modulation can be given by

$$p_{e2el}\approx\frac{3}{2}Q(\sqrt{2\min(|h_{al}|^2,|h_{bl}|^2)P/N_0}) \tag{6}$$

Because Q function is a decreasing function w.r.t. $\min(|h_{al}|^2,|h_{bl}|^2)$, so the selection criterion for BPSK modulation (5) can be replaced by

$$k=\arg\max_{l}(\min(|h_{al}|^2,|h_{bl}|^2)) \tag{7}$$

Let $x_{l1}=|h_{al}|^2 P/N_0$, $x_{l2}=|h_{bl}|^2 P/N_0$, the probability density function (pdf) of x_{l1} and x_{l2} are exponential distribution with mean of $\Omega_{ar}P/N_0$ and $\Omega_{br}P/N_0$. The pdf and cumulative distribution function (cdf) of $\min(|h_{al}|^2,|h_{bl}|^2)P/N_0$ which is denoted by $x_{l\min}$ can be given by:

$$\begin{aligned} f(x_{l\min}) &= \frac{2(\Omega_{ar}+\Omega_{br})N_0}{\Omega_{ar}\Omega_{br}P}\exp(-\frac{2(\Omega_{ar}+\Omega_{br})N_0}{\Omega_{ar}\Omega_{br}P}x_{l\min}) \\ F(x_{l\min}) &= 1-\exp(-\frac{2(\Omega_{ar}+\Omega_{br})N_0}{\Omega_{ar}\Omega_{br}P}x_{l\min}) \end{aligned} \tag{8}$$

For relay selection will choose the maximum value x_k among $x_{1\min}\ldots x_{L\min}$, the cdf of x_k can be given by

$$P(x_k)=p(max(x_{1\min},...,x_{L\min})<x_k)=\prod_{i=1}^{L}p(x_l<x_k)=1-\exp(-\frac{2(\Omega_{ar}+\Omega_{br})N_0}{\Omega_{ar}\Omega_{br}P}x_k)^L \tag{9}$$

Thus, the SER of the SER minimized relay selection for BPSK modulation can be given by

$$\begin{aligned} P_{e2e-rs} &= \int_0^\infty \frac{3}{2}Q(\sqrt{2x_k})dP(x_k)=\int_0^\infty \frac{3}{2}Q(\sqrt{2x_k})d(1-\exp(-\frac{2(\Omega_{ar}+\Omega_{br})N_0}{\Omega_{ar}\Omega_{br}P}x_k)^L) \\ &= \frac{3}{4}\sum_{p=0}^{L}C_L^p(-1)^p\frac{1}{\sqrt{1+2p(\Omega_{ar}+\Omega_{br})N_o/(P\Omega_{ar}\Omega_{br})}} \end{aligned} \tag{10}$$

At high SNR region, Eq. (10) can be further simplified as

$$P_{e2e-rs}=\frac{3(\Omega_{ar}+\Omega_{br})^L(2L-1)!}{2\Omega_{ar}^L\Omega_{br}^L(L-1)!}(P/N_0)^{-L}+o((P/N_0)^{-L}). \tag{11}$$

So we can see that the proposed scheme can achieve full diversity order at high SNR.

5. Simulation Results

In this section, we discuss the system performance through numerical investigations and simulations. We assume the channels are independent flat rayleigh fading channel, and BPSK modulation is employed. Meanwhile the power of all the node are P and noise power are N_0.

Fig. 2 shows the SER of PNC based on SER minimized relay selection when the relays number are 1, 2, 3 and 4, respectively. It can be seen that the simulation results is consistent with the analytical ones. When L=1, SER is the single relay PNC's SER. As the relay number L increases, SER quickly decreases and diversity gain increases with L. To make SER achieve 10^{-3}, P/N_0 need to achieve 28dB when L=1. While 12dB is just needed when L=4. Thus, the SER minimized relay selection is a valid scheme to enhance the PNC's performance.

The effect of relay location is investigated in Fig. 3. Let d_{ar} denote the distance between A and R, and d_{br} denote the distance between B and R. For the distance between A and B is fixed, without loss of generality, we assume $d_{ar}+d_{br}=1$. Meanwhile we set the path loss exponent as four, and we let $\Omega_{ar}=d_{ar}^{-4}$, $\Omega_{ar}=(1-d_{ar})^{-4}$.It can be seen that simulation results match the analytical ones. It also can be seen that the SER performance is best when R is in the middle of A and B.

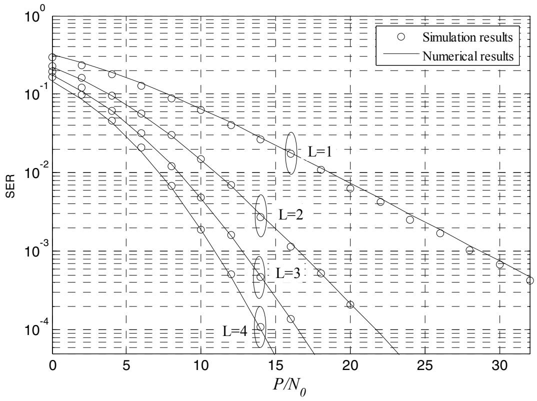

Fig. 2. Simulation Results of SER Minimized Relay Selection Scheme for BPSK Modulation where L=1,2,4,8.

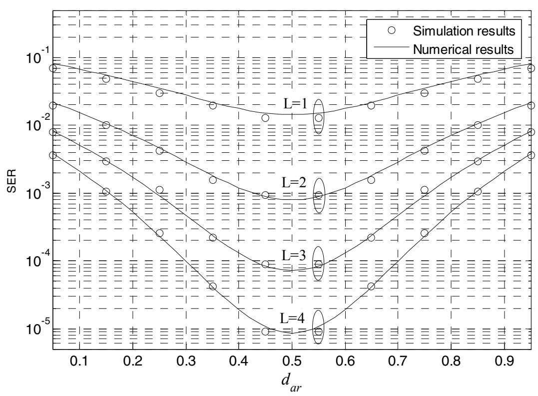

Fig. 3. Simulation Results aginast d_{ar} where L=1,2,4,8 and $P / N_0 = 5\text{dB}$

6. Conclusion

In this paper, we studied the relay selection performance for two-way relay model of PNC. The proposed SER minimized relay selection scheme could select a best relay to minimize the SER of PNC. For BPSK modulation, we derived the selection scheme and the close-form SER expression. From the analysis and simulation, it can be seen that full diversity order can be derived if all the relays are used.

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